

P / REFERENCES OF DESIGN

ENVIRONMENTAL SUSTAINABILITY PRACTICES IN PRODUCT DESIGN FIRMS.

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ABSTRACT | In the quest for sustainable production and consumption and the shift towards an alternative economic framework, design emerges as a crucial actor. Design discipline significantly influences the creation of products, services, and businesses. This study explores the adoption of environmental sustainability and circular economy principles in product design companies, examining the application of strategies, methods, and tools. Through a recent semi-systematic literature review spanning 2018-2023, this research analyses the practical challenges design firms face in the real world. Interviews with six Italian professionals from five product design companies were also integrated, presenting an overview of current applied practices, emphasising the gap and similarities between academic theories and industrial implementations. This paper concludes by suggesting actions and possible directions to design for low environmental impact, drawn from contemporary literature and practitioners' experience. Furthermore, this work calls for design research efforts to be more connected to applicable design practices, be monitorable over time, and tackle significant advances concerning a transition towards sustainability.

1. Introduction

As an evolving field, design is increasingly acknowledged for its potential to drive the transition towards more sustainable economic models (Ceschin & Gaziulusoy, 2019; Moreno et al., 2016). In the last decade, design integration into business configuration and innovation has been recognised as a strategic way to achieve and maintain a competitive advantage (Brown, 2012; Design Council, 2011; Martin, 2009). Today, the role of design goes beyond problem-solving and product innovation. The design practice is progressively seen as a catalyst for sustainable solutions ranging from material and artefact creation to positively influencing sociotechnical systems (Ceschin & Gaziulusoy, 2019). Furthermore, the ability of design to guide companies in aligning with government policies and adopting the circular economy paradigm is an area of active exploration.

In product development firms, design is primarily recognised for decision-making that defines the characteristics of the artefacts. The product design decisions, which encompass material selection, form, and processes, profoundly influence user experiences and behaviours and, significantly, the environmental impact of products. Public sources like the Ellen MacArthur Foundation (EMF, 2013) and the European Commission (EC, 2022) often remark that 80% of a product's environmental impact is determined by choices made in the design phase. As a result, designers, academics, and governments have been developing approaches to implement environmental requirements in the product development process (Ambrosio & Vezzoli, 2019; EC, 2005, 2009; UNEP, 2006). Furthermore, directives and consumer awareness push for design solutions that adopt approaches and strategies that reduce environmental impact (Delmas & Burbano, 2011) and align with the circular economy.

There is a growing interest and development of methodologies, frameworks, and tools created to align industrial product design with sustainability (Rossi et al., 2016). These approaches are widely discussed in academia and scientific literature (Clark et al., 2009; Vezzoli & Sciama, 2006; Vezzoli, 2018); however, they still pose several challenges in practical implementation for corporations and entrepreneurs.

Our study provides an overview of design approaches for environmental sustainability, here intended as Design for Sustainability (DfS) (Vezzoli, 2018), and their practical rolling-out to inform the challenges faced by product design firms in their implementation. We combine a contemporary semi-systematic literature review (from 2018-2023) with insights from five product design companies. This dual perspective enables an in-depth exploration, unfolding reflections on the real-world effectiveness of academic concepts. As a result, we highlight the practical aspects and limitations of design approaches for sustainability and circularity, fostering reflections for developing and implementing new practices that can overcome these limits. We aim to identify and share DfS approaches used in companies and the causes that limit their implementation, offering insights into new directions and bridging the gap between theory and practice.

The study is guided by two research questions: What is the current situation of product design firms in implementing environmental sustainability practices? and What are the practical limitations of applying the theoretical approaches (related strategies, methods, and tools) in business contexts?

The remainder of this paper is structured as follows: Section 2 provides the groundwork for our study. Section 3 describes our methodological approach. Section 4 presents the results and discussion suggesting new directions. Section 5 concludes the paper, summarising the research and limitations.

2. Theoretical Foundations

The earnest attempt to support companies in implementing environmental requirements in product and service design is increasing (Rocha et al., 2019). This tendency has been augmented by consumer awareness (Testa et al., 2021) and stringent global legislative reforms (Shahbazzpour & Seidel, 2006). This phenomenon calls for a closer examination of the relationship between business models and product and service design, as they are inevitably linked to production and consumption.

Integrating environmental and social factors into design criteria now stands alongside traditional considerations like profitability, functionality, aesthetics, and ergonomics (Gaziulusoy, 2015). Although the discussion on DfS is not new, the current context requires more than ever solutions towards a future that preserves the Earth's systemic stability (Richardson et al., 2023).

For several decades, environmental sustainability in design has been considered a critical issue (Papanek, 1971). The 1980s saw the introduction of green design concepts in product design firms, paralleling a rise in public ecological awareness. At the product level, these interventions were desired to mitigate the environmental impact of individual products (Madge, 1997). From the 1990s, the focus shifted to designing products with minimal environmental impact. This perspective started to be commonly recognised as Design for Environment (DfE), Ecodesign, product Life Cycle Design (LCD), or product Design for Environmental Sustainability (Manzini & Vezzoli, 2003; Sarkis, 1998; Sun et al., 2003; C. Vezzoli, 2014; C. Vezzoli & Sciama, 2006). These perspectives evolved by broadening the scope to more social approaches, and Design for Sustainability emerged. DfS start to gain popularity, encompassing the social component with the expectation of significantly advancing sustainable development (UNEP, 2006).

Although DfS adopts social factors, these strategies gained recognition from companies seeking to reduce the environmental impact of their products while considering the broad perspective of sustainability. In this regard, the early 2000s saw a popularisation of philosophies for designing products with low environmental impact (Rossi et al., 2016). These approaches intend to guide the design process through associated strategies, methods, and tools. The European Commission directives (EC, 2005, 2009) reinforced these concepts, targeting manufacturers of energy-related products to promote energy efficiency and reduce consumption. Following this, directives and international standards like ISO 14006 (ISO, 2011) were aligned to ensure global best practices in sustainable product life cycle management.

Recently, the European Commission launched a proposal called Ecodesign for Sustainable Products Regulation (ESPR) (EC, 2022), representing a notable progression towards sustainable and circular product designs. This regulation redefines product design to align with ecodesign principles and the Circular Economy (CE) (EMC, 2013). The CE model minimises resource extraction and maintains resource value within the system for as long as possible (Suárez-Eiroa et al., 2019). The CE promotes design practices focusing on durability, reparability, and resource efficiency. This model encourages firms to embed Circular Design (CD) into their development processes. In this context, CD can be defined as creating products focusing on material cycles and the intended business model to ensure sustainability and resource efficiency (Moreno et al., 2016).

Under the CE framework, CD has been established to protect economic and environmental values by moving away from the take-make-waste model (EMF, 2013). At the same time, ecodesign or DfS (focus on ecological requirements) encompasses a spectrum of activities that aim to reduce the impact of products (and services) to facilitate the transition to sustainable production (Vezzoli, 2018). Even if DfS has a more robust background and CD in business is in its early stages, this study considers both valid approaches to support companies in transitioning towards low environmental impact design.

3. Methodological Approach

To comprehensively understand the implementation and limits of DfS and CD in product design firms, this study adopts a dual-method approach, combining (a) a semi-systematic literature review (SSLR) complemented by (b) semi-structured interviews. A gap was identified in the literature, where structured theoretical frameworks were found, but there was also a lack of detailed information on how companies apply these theories in practice and their challenges. To bridge this gap, interviews with practitioners were conducted to directly explore the real-world application of sustainability practices. Prioritising peer-reviewed literature ensured academic rigour and established a solid theoretical foundation in environmental sustainability within product design. Although industry reports offer insights into current practices, their varied methodologies and transparency levels could introduce inconsistencies in the theoretical basis of this research. Semi-structured interviews were chosen to capture the practical applications of theoretical approaches, aiming to gather qualitative insights not typically available in public or academic reports.

3.1 Preliminary Studies and the SSLR

Preliminary desk research was performed using secondary data to analyse the general ground (Verschuren & Doorewaard, 2010). Literature databases and online sustainability reports from product design companies were considered to map the interest and efforts on low environmental impact. This information provided a conceptual background for the study. However, a lack of information about the current challenges of theoretical frameworks was found in this process, driving the formulation of research questions (Jeyaraj, 2023). The following inquiries motivate the study: (1) What is the current situation of product design firms in implementing environmental sustainability practices? (2) What are the practical limitations of the theoretical approaches (related strategies, methods, and tools) in real business contexts?

For a more systematic understanding, ensuring consistency to the study's scope, a SSLR, as described by Snyder (2019), was undertaken. This qualitative approach began with a selection of keywords derived from the preliminary desk research and motivated by the research questions.

Database and Search Syntax

The keywords were combined using Boolean operators to create strings and conduct the SSLR process. The selected databases were Scopus, ScienceDirect, and Google Scholar, which were chosen for their comprehensive coverage of academic research. The timeframe for the search was deliberately set from 2018 to 2023 to encompass recent literature. The process was finally conducted between November and December 2023. Only peer-reviewed documents were searched, given their academic rigour. Limit source types were articles, reviews, and conference papers. Furthermore, English language publications were selected to ensure the accessibility of the literature.

Titles, abstracts, and keywords of documents were the target. The search terms were tailored to each database's unique syntax and search capabilities. For Scopus, one string was used. In ScienceDirect, two variations were tested for effectiveness. In the case of Google Scholar, the search was restricted to review articles to exclude non-peer-reviewed material such as books or student theses, which may not meet the scholarly criteria required for this study. A global search was conducted to capture diverse, worldwide practices. Table 1 presents the tailored keywords and search strings for each database.

Table 1. String used for each database.

String	Database
("compan*" OR "firm*" OR "SMEs") AND ("product design") AND ("ecodesign*" OR "circular*" OR "sustainab*") AND ("challenges" OR "barriers" OR "implementation") AND ("strategies" OR "tools" OR "methods"))	Scopus
("company" OR "SMEs") AND ("product design") AND ("eco-design" OR "sustainable") AND ("challenges" OR "barriers") AND ("tools" OR "methods")	ScienceDirect
("company" OR "SMEs") AND ("product design") AND ("eco-design" OR "sustainable") AND ("challenges" OR "barriers") AND ("tools" OR "methods")	
intitle: (("company" OR "companies") AND ("product design") AND ("sustainable design" OR "ecodesign") AND ("challenges" OR "barriers" OR "implementation") AND ("strategies" OR "tools" OR "methods"))	Google Scholars

Selection Criteria

The databases yielded varying articles. They were refined by excluding irrelevant subject areas and using the available automatic filters. The focus was explicitly on physical products within various product design sectors, excluding digital-only products. One hundred forty documents were imported into Zotero to speed up the process. Initially, duplicates were removed. The documents were skimmed by titles, keywords, and abstracts, with those considered outside the scope immediately discarded. This process prioritised studies involving tangible products across diverse yet interconnected domains, such as consumer goods, industrial equipment, and furniture.

The remaining articles were assessed against selection criteria, focusing on:

- Design for environmental sustainability approaches and/or circular practices in product design firms (or real-world projects) enhancing low-impact solutions;
- At least one approach to environmental sustainability or circular practice implementation in product design real-world;
- Specific challenges or barriers in adopting sustainable and circular design approaches;
- The gap between theories and practical implementation.

A more thorough examination of abstracts and keywords further narrowed the final selection of articles for a full review. The selection process is illustrated following a PRISMA flow diagram (PRISMA, 2020)

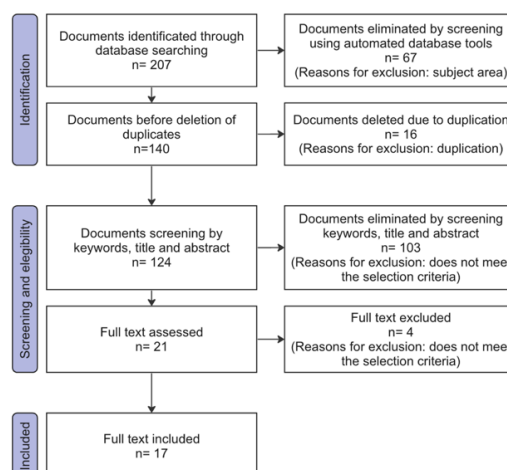


Figure 1. PRISMA flow diagram adapted for this research.

Content analysis was employed to synthesise the collected data outlined by Duriau et al. (2007). Excel spreadsheets and Miro boards were used to catalogue the documents and construct mind maps, aiding in the reflection and categorisation of the findings. Colour coding enabled a more systematic identification and reporting of patterns.

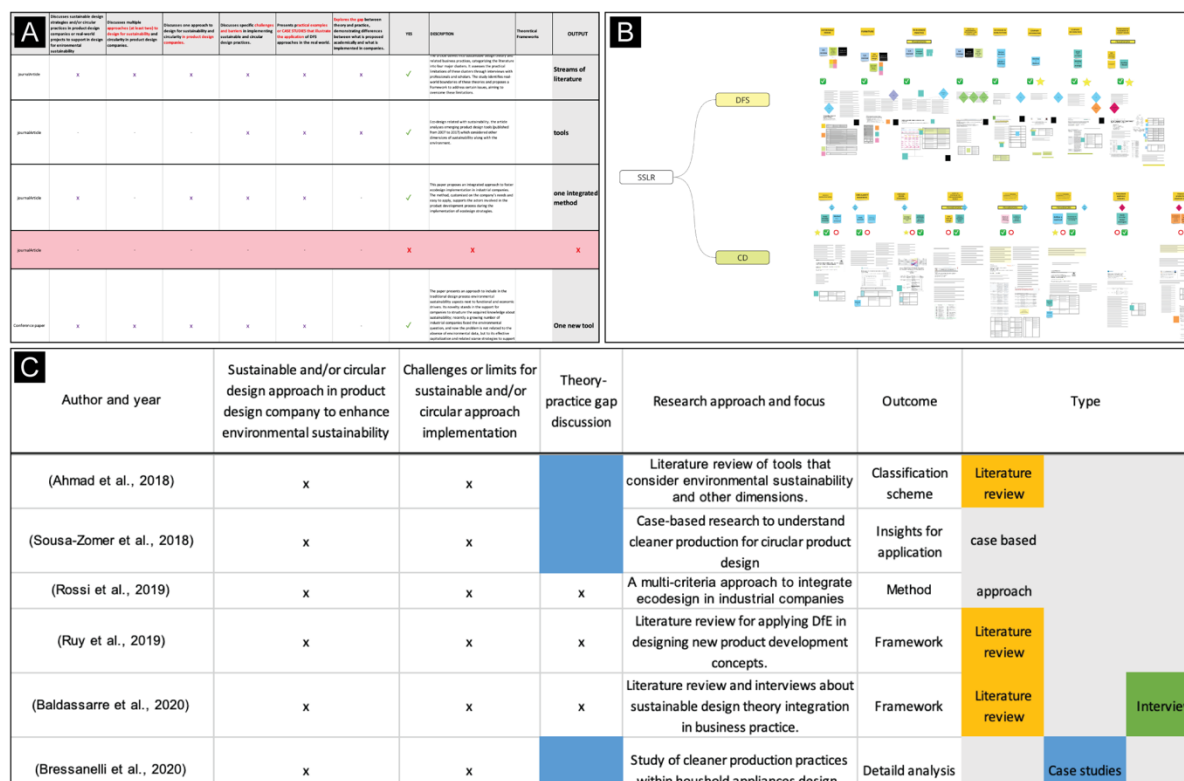


Figure 2. Screen capture of the data organisation and analysis process. (a) Excel spreadsheet for selection of articles. (b) Miro board mind map and colour coding. (c) Excel spreadsheet for content analysis and categorisation.

3.2 Semi-Structured Interviews

After collecting insights from the SSLR, semi-structured interviews were conducted to gain a profound and real-world understanding of the issue under study. As Adams (2015) described, this method allows for an in-depth exploration of professional experiences, opinions, and knowledge. These interviews aimed to uncover details outside of the literature. As Gugiu and Rodríguez-Campos (2007) indicated, an interview protocol was designed to guide the data collection and increase the reliability of the study.

The selection criteria for companies were highly pragmatic. Although they do not represent the whole sector or a worldview, they constitute a relevant sample for the study. Firms with proven readiness and consent to share in-depth information about their sustainability efforts in design, challenges, and achievements were selected. Furthermore, the geographical location was essential to allow fast communication and the possibility of face-to-face follow-up meetings.

Interviews were programmed remotely via video conference software to accommodate participants' locations and schedules. The interviews were carried out during December 2023 and February 2024. Each session lasted approximately 50 minutes and was audio-recorded with participants' consent. Transcription, coding, and thematic analysis were conducted to identify patterns and results.



Figure 3. Interview analysis processes. (a) transcription and thematic identification. (b) coding and pattern identification.

4. Results and Discussion

4.1 General Analysis

Seventeen documents met the eligibility criteria. Each contributes to the discourse on low environmental impact practices in product design companies. The selected documents illustrate approaches, their implementation in practice and the challenges of their adoption. A direct discussion of the theory-practice gap is not uniformly presented. Nevertheless, the complexity of applying theory in practical settings is a recurring theme in all contributions. Table 2 illustrates an overview of the result of the selected literature, highlighting the research method, outcome, and lens.

We divided the literature selected between studies under the lens of circularity, with nine results and those over environmental sustainability, with eight results. This parity suggests that both concepts are acquiring equivalent attention among companies in the discourse on designing with a reduced environmental impact.

Table 2. Overview of the literature included in the semi-systematic review.

Reference	Research approach	Outcome	Lens	
			Circularity	Sustainability
(Ahmad et al., 2018)	Literature review	Classification scheme		x
(Sousa-Zomer et al., 2018)	Case-based research	Insights for application	x	
(Rossi et al., 2019)	Method development	Method		x
(Ruy et al., 2019)	Literature review	Framework		x
(Baldassarre et al., 2020)	Literature review and interviews	Framework		x
(Bressanelli et al., 2020)	Literature review	Detailed analysis	x	
(Bumgardner and Nicholls, 2020)	Literature review	Literature analysis		x
(Lindkvist Haziri and Sundin, 2020)	Mix methods approach	Framework	x	

(Benabdellah et al., 2021)	Literature review	Model	x
(Boorsma et al., 2021)	Literature review and interviews	Method	x
(de Kwant et al., 2021)	Literature reviews and case studies	Framework	x
(Hansen and Schmitt, 2021)	Literature review and case studies	Framework	x
(Hildenbrand et al., 2021)	Case study research	Insights for application	x
(Valusyte, 2021)	Literature review and case studies	Explanatory diagram	x
(Boorsma et al., 2022)	Literature review and co-design sessions	Method	x
(Delaney et al., 2022)	Literature review	Framework	x
(Rossi et al., 2022)	Method development	Method	x

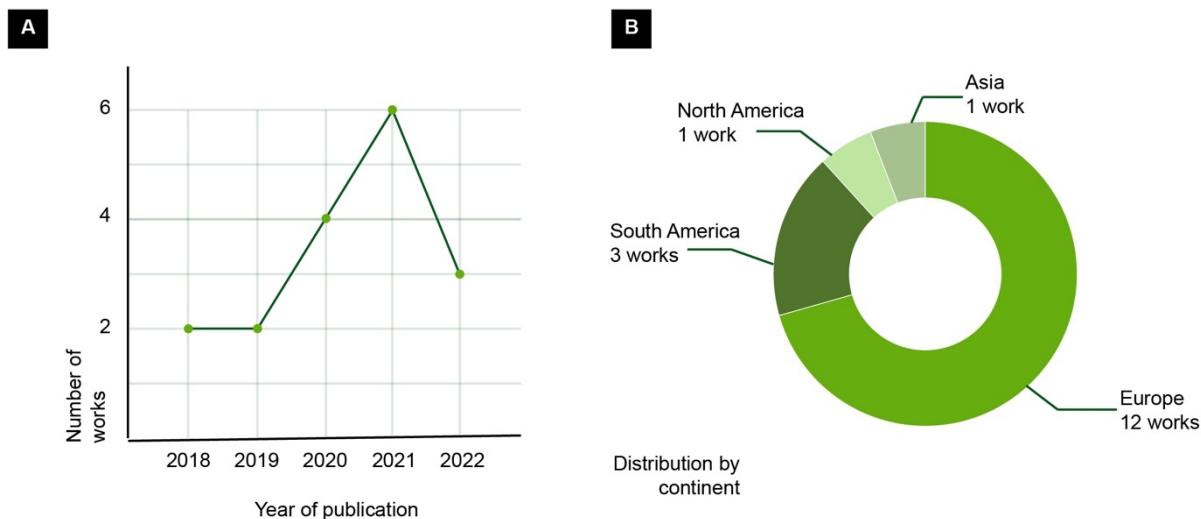


Figure 4. Literature reviewed general analysis: (a) publications per year; (b) publications by continent.

Figure 4A outlines an increasing growth in the studies on low environmental impact within design companies, with most publications from 2020 and 2021. Furthermore, while the discourse aimed to be analysed globally, Figure 4B demonstrates a concentration of research in the European continent. The analysis revealed frequent interchangeable use of terms such as 'approaches,' 'strategies,' 'methods,' and 'tools,' potentially leading to ambiguity. To clarify, we adopted the following definitions:

- Approach: A perspective-driven way to address a problem. The most general of these terms;
- Strategy: A structured plan to achieve specific goals;
- Method: A systematic procedure applied to a task;
- Tool: An instrument that facilitates the application of methods or techniques.

From the seventeen identified documents, ten were primarily focused on strategies, three concentrated on methods, two examined specific tools, and two offered a broad overview of the evolution of approaches relating to design application in firms. In the next section, we present the SSLR results divided into the abovementioned terms and under the sustainability and circularity lenses.

4.2 Literature Review

Sustainability Lens

As outlined in the introduction, the concept of environmental sustainability has been recognised in the product design industry for a considerable time, manifested through different labels. Two perspectives representing low-impact design in the literature review are DfS and Design for the Environment. DfS (focusing on environmental requirements) involves a more comprehensive approach, considering social, economic, and environmental goals in product design, demanding broader changes in business and society. DfE focuses on reducing environmental impacts through specific technical improvements (Delaney et al., 2022).

Delaney et al. (2022) and Bumgardner and Nicholls (2020) have extensively contributed overviews on this topic, identifying numerous approaches for embedding these perspectives into the product design process. The former provides a holistic view of recurrent factors when designing for environmental sustainability. They emphasise the integration of DfS in products and the use of tools like LCA, checklists, and software, underlying the challenges in integrating them, such as the significant time and quantitative data required and the need for specialised expertise. In this regard, they present a new design process for and from product designers, integrating stages on how and when to consider the identified environmental sustainability factors. The latter, instead, present DfS practices in wood furniture, remarking on the complexities these principles impose, for instance, adding steps and costs to the design process. They investigate approaches like green manufacturing, green supply chains, ecodesign, sustainable materials, biomimicry, and eco-labelling, highlighting their influence on firm competitiveness.

Three articles propose strategies as innovative DfS frameworks. Baldassarre et al. (2020) discuss the need to integrate DfS theory into business, noting the challenges of abstract philosophies in ecodesign, product service systems, business models, and collaborative ecosystems. The problems they highlight are linked to specific, actionable guidance, the enormous change needed in the operating company system, the financial costs, the lack of stakeholders' commitment to sustainable goals, and the rebound effects of poorly studied strategies. Furthermore, the limits in communication and language between the academy and industry are evidenced. In this regard, they integrate existing DfS theory into a new framework within business concepts and give some recommendations to deal with these issues. Ruy et al. (2019) describe a framework for implementing DfE in the conceptual design phase, highlighting the need for environmental assessment approaches applicable across product concepts. His framework is based on an analytical hierarchy process for conducting product concept evaluation, determining which approaches will help achieve environmental performance. This framework is mainly based on strategies related to the physical dimension of the product, represented by the use and consumption of material resources. Lastly, Benabdellah et al. (2021) acknowledge the lack of specific classification to consider suitable methods for DfS. To overcome these challenges, they suggest a strategic framework to integrate Design for X with knowledge management (KM) techniques. The authors propose using KM and an ontology-based approach (Ali et al., 2020) for a more structured environmental consideration when designing.

Rossi et al. (2019) and Rossi et al. (2022) present new methods to improve the practical application of ecodesign in industry. In the first article, it is noted that prioritising legal, performance, cost and aesthetic factors over environmental considerations creates a barrier to integrating sustainability into business and design practices. The authors suggest the "Product Impact Index" method for aligning these priorities with environmental objectives, improving the evaluation and comparison of possible solutions. On the other hand, the second article discusses the need to support companies in integrating their productive data related to environmental, functional, and economic aspects into the design process. They propose using this information and making more environmentally aware decisions.

Finally, Ahmad et al. (2018) analyse existing tools for DfS, noting their failure to integrate environmental, social, and economic sustainability, evidencing the need for approaches encompassing a broader sustainability scope in the design processes. They classify tools published from 2007 to 2017, highlighting an inconsistency in using those tools and suggesting a gap in similar, more recent research.

Circularity Lens

The analysis shows that CE and CD, aiming for zero-waste products, are still in the early adoption stages in product design companies. Furthermore, the review suggests a broader consideration of strategies to reach CE through CD and less focus on tools or methods. Indeed, Sousa-Zomer et al. (2018) note that the ground of CE and CD is still unexplored in business. They claim that using cleaner production (CP), a known principle, can help the CE, especially in product design (even if it is not a strictly design-related area). They found CP practices key for CE at both product optimisation and micro-level production stages, linking to broader CE aspects like waste management and other organisational processes.

Lindkvist Haziri and Sundin (2020) and Boorsma et al. (2021) both advocate for the design of a remanufacturing (DfRem) strategy to improve environmental sustainability within CD. The former proposes a framework addressing DfRem challenges, particularly the feedback loop from remanufacturing to design, aiming to systematise this feedback into the product design phase for better DfRem application. The latter stresses the need for early integration of remanufacturing principles in design, citing challenges like technical integration and scalability. They note a disparity between the theory and practice of DfRem, suggesting that design management is crucial for bridging this gap. Both studies initially validate their proposed frameworks but emphasise the lack of additional testing and refinement.

Bressanelli et al. (2020) review CD strategies in the appliance sector, noting their ineffective integration in the design process. They stressed the incremental adoption of strategies like the 4R hierarchy, servitisation, and digital tech use. However, they identify challenges such as reduced efficiency from incomplete 4Rs implementation, issues like the complexity of service-based models, operational challenges, scalability difficulties, and investment risks in new technologies. On the other hand, Valusyte (2021) presents an overview of the implementation of CD strategies in manufacturing, noting their growing recognition but limited real-world use, especially in SMEs. The author points to a reactive rather than preventative approach to value chain impacts. Key challenges include terminological confusion across different fields and insufficient information on the practical application of CD.

De Kwant et al. (2021) and Hansen and Schmitt (2021) introduce strategies to facilitate CD implementation, addressing its underexplored role in business models and product innovation. De Kwant et al. focus on a framework to identify cost, cultural, and policy barriers and integrate DfS theory with circular business principles. On the other hand, Hansen and Schmitt identify barriers like designer mindsets and supply network issues, proposing "innovation communities" for more humanistic and collaborative solutions to circular product innovation challenges. They suggest collaboration and networking with diverse stakeholders are necessary for succeeding in sustainability-oriented innovation.

Introducing methods, we found Boorsma et al. (2022) that decided to evaluate circularity at the product level, reflecting on the designers' readiness level for implementing CD. They state that transitioning from linear to CD demands a new designer mindset for developing multi-use cycle products. They propose the "Circular Product Readiness" method to compare CD scenarios and apprise designers' capabilities in CD, identifying strengths and areas for improvement.

Lastly, regarding CD tools, Hildenbrand et al. (2021) point out that most existing products are not designed and manufactured with circularity concepts that consider consumer use, nor the existing tools for design. Thus, they examine the implementation of two tools within real-world case studies to understand strategies within CD that consider users and the end of use. They emphasised user interaction and feedback as fundamental to achieving circularity.

4.3 Interview Findings

The interview results consolidated empirical information gathered from six testimonials from Italian practitioners within Italian design firms (two for the same company). We explore their approaches for design with low environmental impact and the challenges of incorporating these principles into their business.

Table 3. Summarised information about the companies (and participants) in the survey.

Company size (workforce)	Design Category	Recognised sustainability and circularity efforts	Role of the interviewer
10,001+ employees	Power suppliers – Technical products – Products for electrification	Application of Life Cycle Thinking (LCT). Transparency and communication.	Global Sustainability Specialist. Senior Designer Engineer in R&D.
201- 500 employees	Design furniture for home and working environments	Sustainability strategies in its production and design process. Certifications and transparency. LCA and redesign.	Sustainability Design Manager.
51-200 employees	Home furniture with meaning – Interior home decor	Application of sustainability as a business philosophy. Incorporation of ESG and SDGs targets.	Product Marketing and R&D projects.
201-500 employees	Notebooks, bags, and accessories	Durable products. Certified materials. Use of recycling or reprocessing strategies. Social programmes.	Global Marketing Manager and ESG team member.
501-1,000 employees	Light Design, Outdoor lighting, and Architectural Lighting	Certifications and transparency. LCA and redesign. SDGs targets. Materials, energies, and health.	Head of Innovation Design and Sustainability team member.

The interviews illustrated the feasibility of addressing sustainability through design and the possibility of rolling-out DfS and CD approaches. However, they underlined the complexities and the need for a deep organisational commitment and a change of mindset not only of individual practitioners but of the whole organisation. The interviewers highlighted that one of the current strategies is the creation of sustainability teams (most of them have achieved this in the last four years or less), recognising the complexity of sustainable decision-making and execution. These teams often include people with extensive knowledge of the company and young professionals from diverse areas. Today, they are proving to be strategic in integrating DfS into the corporate culture and addressing the progressive evolution of practices. Multidisciplinary collaboration was recognised for fostering robust dialogue on sustainable challenges and innovations.

A demand for new professionals with a holistic understanding necessary for pragmatic implementations was revealed. There is a growing inclination towards internalising designers with technical skills, like LCA proficiency, to enhance in-house capabilities and create bespoke sustainability models. Indeed, despite the struggle to find such candidates, four of six participants recognised the implementation of this knowledge internally and the development of tools for their design development process. Participants underscored

that firms are developing customised toolkits, guidelines, and checklists and using LCA to measure the impact with external consultancy support. LCA emerged repeatedly, evidencing an essential first step for guiding design, processes, impacts, and ensuring the consistency of successful strategies across various product lines.

LCA was also related to compliance and the standards or certificates companies aim to achieve. For example, participants emphasised following ISO 14040:2006 for Life Cycle Assessment and ISO 14006:2020 for environmental management systems and incorporating ecodesign (ISO, 2006, 2011).

Participants point out annual training courses as necessary, emphasising effective communication on sustainability topics across different practice areas. Furthermore, most of them expressed that agenda creation for sustainability and KPIs related to product development issues were considered necessary. Indeed, the interviewers say there is a need for strong partnerships with other companies and alignments with suppliers, sharing their sustainability objectives.

Unique insights include forming "good practice books" and "material libraries" and suggesting tools for archiving and learning from past successes and collaborations. Participants define this approach as instrumental in fostering continuity and progress in DfS practices.

Materials design and innovation, particularly the exploration of emerging, bio-based and recyclable options, surfaced as a strategic priority for sustainable and circular design strategies. Yet, reconciling environmental benefits with aesthetic and durability standards presents a significant ongoing challenge and an area ripe for further research that, as interviewers claimed, is already on their agendas. Indeed, in some cases, creating product-service system options is necessary to keep materials in the loop.

Despite progress, ongoing and evolving challenges report the need to continually develop skills, tools, and collaborative efforts to integrate sustainability fully into product design and business strategy. The resulting practices adopted by companies to advance the design of low environmental impact are the following:

- Formation of multidisciplinary and transversal teams equipped with specialised skills;
- Onboarding of professionals with related expertise and internalisation of such competencies;
- Measure impacts as a starting point for undertaking sustainable initiatives;
- Creation of tailored tools and methodologies;
- Create/propose services that complement sustainable product offerings;
- Continuous internal training and knowledge updates;
- Clarifying internal terminology related to sustainability;
- Engaging partners and suppliers in shared sustainability objectives and KPIs;
- Creation of a sustainability agenda;
- Compiling best practices;
- Adhering to legislative requirements and pursuing relevant certifications and standards.

4.4 Integration of Findings, Reflection, and Future Directions

We discovered convergence in implementation and challenges but also recognised a gap still evident within theory and practice.

The literature review reveals a critical paradox: the abundance of conceptual frameworks, strategies and tools focusing on environmental requirements in product design contrasts with few long-term reports on their application in companies. On the other hand, the growing literature on CE shows a limited and superficial focus on the physical part of the product design, even though it is essential in this new economic model (Heras-Saizarbitoria et al., 2023).

Within the literature, we found that despite admirable but isolated efforts, DfS and CD often fail to create meaningful impacts that can effectively integrate product design with strategic business objectives. The theoretical exploration of DfS and CD is well documented, but practical applications in business are sporadically reported, leading to a fragmented understanding of its application. While case studies may shed light on specific instances of practice, they provide only snapshots, leaving a notable gap in longitudinal research (or long-term approaches) that could reveal how organisational practices and strategies evolve over time. We recommend that future literature integrate sustainable product design principles within company culture objectives and practical operations.

With the review, we identified multiple (less or more complex) tools and methods, such as LCA, sustainability checklists, and software packages, to aid low-impact design. Nonetheless, these tools encounter significant barriers, including complex data requirements and the need for designer expertise, pointing to a misalignment between tool availability, their practical use in design processes, and the practitioners' skills. More simplified methods and tools are often criticised for not being sufficiently accurate. The specific ones, instead, receive criticism for not being scalable. Additionally, a prevalent issue of terminological confusion on definitions among sustainability and circularity concepts and the usefulness of methods and frameworks often limits effective communication among academics, educators, and practitioners. These findings are consistent with interview testimonials. Participants encountered challenges performing LCA or using ecodesign softwares without consultant support or dedicated professionals. They also expressed that academic or generic tools and methods are not always efficient, but creating their own following the firm requirements and values demonstrates more effectiveness. It is therefore suggested that developing flexible, updatable ad hoc models inside firms could be a good direction for future development.

Furthermore, interviewers also indicate confusion in vocabulary. However, they were mostly aligned with terms of Ecodesign directives (EC, 2009). This repeated claim suggests that even with the present efforts for alignment in communication, more rigour is necessary. A good initiative could be to vigorously implement the terms indicated by the "International Organization for Standardization" (ISO, 2006).

The literature review and interviews continuously stressed that stakeholder involvement is crucial for successfully adopting DfS and CD and establishing R&D partnerships with shared KPIs. Furthermore, collaborative environments, multidisciplinary teams, and visionary management were repeatedly found essential for achieving environmental requirements in product outcomes. It would be interesting to analyse and share more information about these teams' formation and work to propose companies' new models. However, they are still emerging, and it is unclear where and how they will operate.

An expected result was confirmed with the literature review, i.e., the importance of incorporating sustainability and circularity principles from the initial stages of the design process. The authors highlighted that this incorporation requires equipping designers with skills and knowledge to navigate DfS solutions effectively within the business implications. In contrast, interview participants emphasise this need differently. They explained that the challenge is integrating sustainable and circular principles into the company's culture and making them imperative in the design process, production, and marketing. Both approaches seem to be valid and compatible. Additionally, some practitioners underscored materials design and innovation as fundamental, advocating that materials are central in all DfS and CD strategies, and there is a growing need for more standardisation and recognition around emerging materials and their potential applications (Duarte Poblete et al., 2024). Future research should analyse them in depth to bring more specific data and results.

Recent literature highlights that barriers such as consumer disinterest and weak regulatory frameworks are progressively being overcome thanks to growing consumer awareness and improved environmental regulation. Indeed, the older literature was characterised by these limits. At the same time, the interviewers revealed that today's consumers, customers, and new legislation are putting pressure on companies to propose design solutions to existing problems and anticipate and prevent new challenges. In this regard, three participants acknowledge that the best way to face this challenge is to see it as a competitive

advantage, where investments will pay off through future innovation. We argue that, despite the difficulties in complying with regulations and standards, they are valuable strategies for achieving concrete goals in environmental sustainability.

While the literature on these fields is broad, empirical research is still needed, emphasising longitudinal studies and deeper engagement with practitioners. This approach could overcome the gap between theory and practice, fostering a more synergistic and impactful collaboration among academia and industry. Sustainability concerns in design business practice are not new (Gaziulusoy, 2015). However, the continuous emphasis on addressing them in recent literature highlights the urgency for industry and academia to join forces. Furthermore, the slow pace of change in business sustainability underscores a need for accelerated action, not just in product design.

By analysing the literature results and the interviews' findings, we address the research questions, i.e., the current situation of product design companies in implementing environmental sustainability practices and the constraints they face in the business world. By examining the data, we have identified key trends, challenges, and strategies for pursuing low-environmental impact design within the industry.

Table 4. Summary of implemented aspects and challenges in product design companies.

Implemented aspects	Common challenges and limitations
Traditional DfS and CD approaches (guidelines, tools, and methods).	Too general. Lack of scalability. Insufficient integration within company culture and operations factors. Complexity of use or understanding of the results. Extensive data requirements. Time consuming. Lack of commitment from users. Complex vocabulary. Expertise required.
Tailored guidelines, tools, and methods.	Time consuming. Large investments. Expertise required.
Principles (e.g., recycle, reuse, reduce, etc.) and strategies (DFX, design for disassembly, design for circularity, etc.)	Incorporation from the initial design stages. Consistency in all projects. Coherence with company culture.
Materials Design & innovation	Harmonise environmental benefits with aesthetic and durability standards. Lack of specific professional profiles. Progressive updates and uncertainty in time.
Directives and standardisation guidelines.	Time consuming. Complex terminology. Lack of knowledge about its success. Continuous updates and insecurity.
Training and awareness regarding sustainability and circularity.	Isolated implementation (just one area of the company). Terminology confusion and ineffective communication across sectors. Time consuming. Lack of a visionary perspective.
New entries, multidisciplinary teams, and collaborative environments.	Lack of specific profiles. Deficit in transdisciplinary skills. Time and resources.
Strategic Partnership	Lack of responsible partnering. Stakeholders' commitment to sustainable practices. Lack of shared objectives and KPIs.
Visionary ESG management	Difficulties in finding experts with holistic/transversal and visionary management vision. Large investments.

5. Conclusions

The literature and testimonials on environmental sustainability approaches and their rolling-out in product design firms were systematically collected and analysed as part of this study. The main aim was to assess the current situation of product design companies in adopting low environmental impact design practices and to understand the practical limitations of the theoretical approaches within the related strategies, methods, and tools. Seventeen works between 2018 and 2023 were analysed following a semi-systematic review process that depicted the literature's contemporary frameworks of DfS and CD. In-depth interviews with practitioners from five Italian companies provided further real-world context. As a result of the study, current practices of DfS and CD adopted by companies to advance low environmental impact design were identified and reported. It also offered insights and possible future directions for companies and academics to enhance DfS and CD and bridge the gap between theory and practice.

Reflecting on our work, future research may address this study's limitations. The literature review was limited by a keyword-based search within scientific databases, potentially excluding emerging studies. Additional methodologies, such as snowballing, could broaden the research scope in future work.

Moreover, the qualitative data collection through the interviews was confined to the Italian industrial sector. Thus, further research in other companies, countries, and continents should be conducted in future studies. The data collected from the interviews does not encompass the entire industrial sector but provides a snapshot of various aspects from different design categories. Additional interviews and observational studies across a broader range of companies are recommended to deepen the understanding of the industry's current state.

Lastly, while structured, the study's qualitative approach to data interpretation is subject to the possibility of alternate analytical perspectives. However, the insights derived from this process contribute meaningfully to the ongoing discourse on implementing sustainability and circularity in design for business practices.

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